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DISCUSSION ON THE RESPONSE OF UNREINFORCED MASONRY TO LOW-AMPLITUDE RECURCIVE LOADS: CASE OF GRONINGEN GAS FIELD

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Abstract. *Unreinforced masonry (URM) is a fragile material that responds to cyclic load reversals in a non-ductile way, unless special measures are taken. Damage occurs in large amplitude loads causing partial or total collapse in some cases, as it was observed in the past earthquakes. Response of URM to recursive, frequent but low-amplitude seismic loads, on the other hand, is a relatively new topic that needs experimental and analytical validation. This paper focuses on Groningen URM buildings that have been subjected to low-amplitude load reversals in the last decades, especially in the very last decade, due to the induced seismicity caused by gas extraction. In the paper, previous experimental findings are reviewed mostly focusing on the range of low amplitudes. An exercise with existing hysteresis rules, trying to find residuals after recursive seismic actions, has been presented.*

1 INTRODUCTION

Groningen is the largest gas field in Europe, and 10th in the world. There has been extensive gas extraction taking place in the region and there are relatively “larger” magnitude induced earthquakes especially in the very last decade. The single-story or two-story houses compose the main building stock in the region. These houses are mostly made of unreinforced masonry (URM), traditionally without considering any seismic action into account because of the inexistence of such phenomena previously in the area. Low normal stresses on the load bearing and veneer walls, as well as the recursive nature of the seismic actions, despite their low amplitude, raise the question of whether micro damages accumulate during years of seismic actions. There is a limited experimental research on the low-cycle fatigue of masonry under recursive loads, but these are tests that were conducted for normal stresses [1, 2]. It was found in the previous research that there is development of micro cracks, and thus there is accumulation of damage in case of low amplitude loading in recursive fashion

This complicated issue requires tiresome numerical but mostly experimental validation. This paper, however, focuses mostly on, by using available experimental data, the URM response in low-amplitude range, as well as requirements of a compatible hysteresis model that can accurately represent both low- and high-amplitude regions of the force-deformation response.

2 SEISMICITY OF THE GRONINGEN GAS FIELD

In the case of seismic events, the stress disturbances that occur during an earthquake are primarily due to natural tectonic processes. In the case of induced seismicity, however, the stress perturbations that are released during an earthquake are majorly due to human activities, as in the case of Groningen. The Groningen gas field is located in an area that is assumed as non-seismic, meaning that the seismic events apart from the induced seismicity, are inexistent.

Regarding the causes of induced seismicity, there are several types of underground activities that may play role. One of the most common causes, however, is the exploitation of land gas fields.

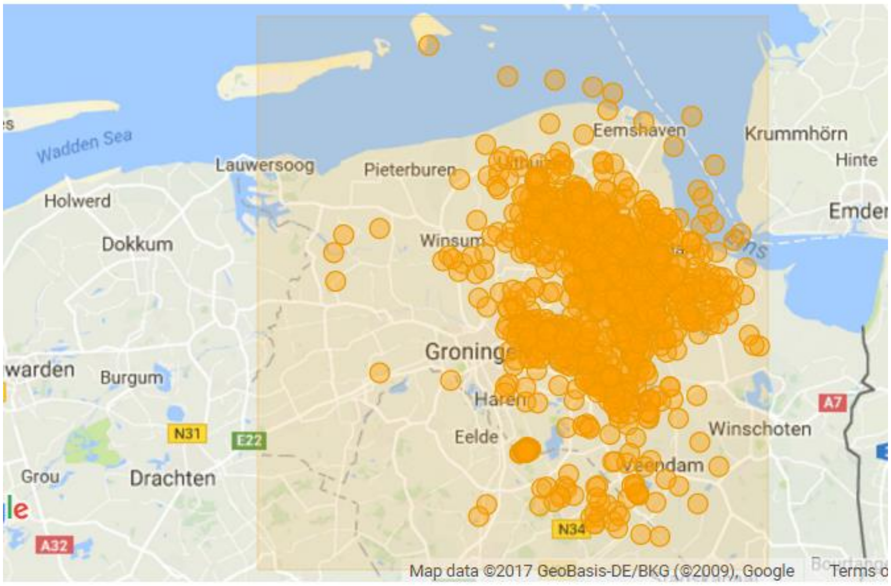

Figure 1: The seismic events obtained from the KNMI Seismic Database for the Groningen region for the time period between 2003 – 2016.

Interestingly enough, no earthquakes were reported from the Groningen area prior to 1991. This can be explained with the assumption that the events were smaller than the humanly perceptible levels.

In Figure 1, the seismic events between 2003 and 2016 in the area can be seen. Distribution of the events in terms of magnitude ranges can be seen in Figure 2. The sudden increase in seismic events between 2011 and 2013 can clearly be observed in that figure.

In Figure 3, the seismic zonation map of the Netherlands is given in accordance with the Eurocode-8. Specifically, the region of Groningen is classified as Seismic Zone A, which corresponds to PGA 9.81 cm/s^2 (0.01 g). This value was exceeded by far during the strong ground motion that was recorded at the Huizinge event on the 16th of August 2012 (Middelstum station). More detailed research on the seismicity of the region, as well as the characteristics of the strong ground motion records can be found in Bommer et al (2015) [3].

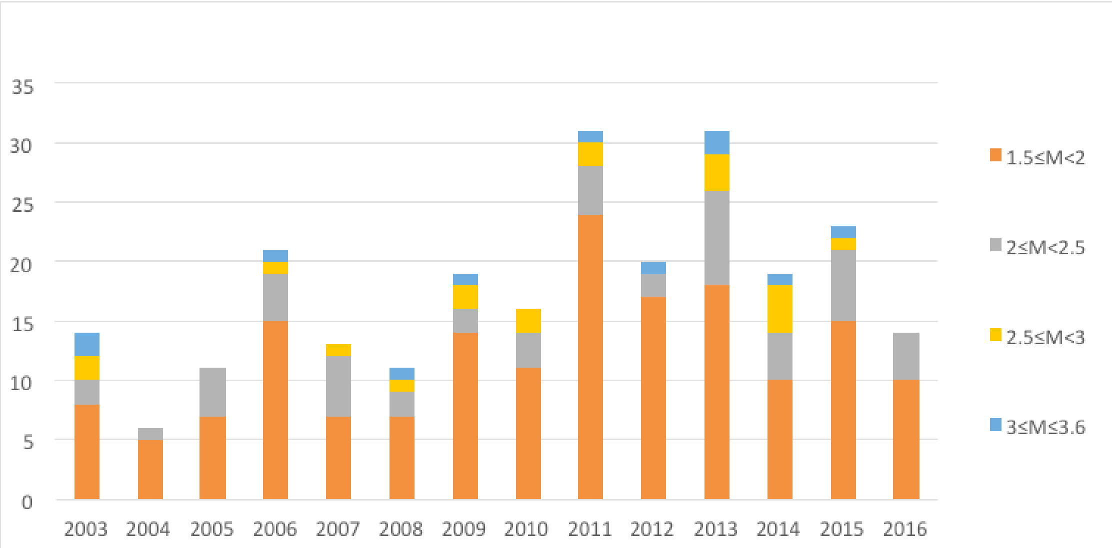

Figure 2: The distribution of the seismic events in a year basis for Magnitude 1.5+.

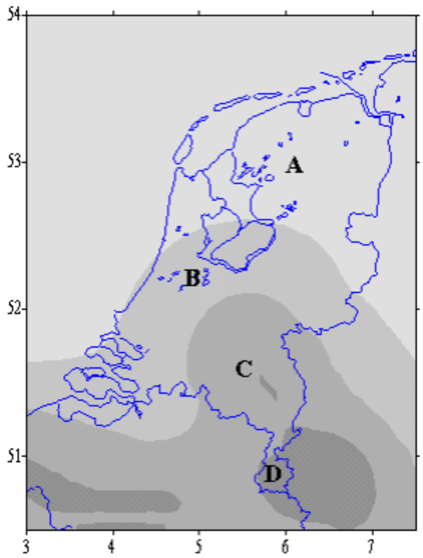

Figure 4: The seismic zonation map of the Netherlands is based on a seismic hazard study with a 10% of exceedance in 50 years (return period 475 years, and A means 0.01g PGA).

3 AVAILABLE EXPERIMENTS ON GRONINGEN-TYPE URM

Experiments sponsored by NAM (Nederlandse Aardolie Maatschappij) and conducted by EUCENTRE (Pavia, Italy) were carried out on full-scale wall specimens resembling the typical calcium-silicate unreinforced masonry walls that can be found in the Groningen region. Specifically, two wall specimens representing a slender and a squat wall, correspondingly, were investigated under in-plane cyclic shear-compression tests. Their characteristic and dimensions are given in the Table 1, and their experimental configurations are shown in the Figure 4. These two specimens were chosen to account for different types of wall that can be traced in real structures are characterized by flexure or shear dominated type of failure.

Specimen	L (m)	t (m)	h (m)	σ_v (Mpa)	Boundary Conditions
Slender Wall	1.1	0.102	2.75	0.52	Double fixed
Squat Wall	4	0.102	2.75	0.3	Cantilever

Table 1: Characteristics and dimensions of the Tested Specimens.

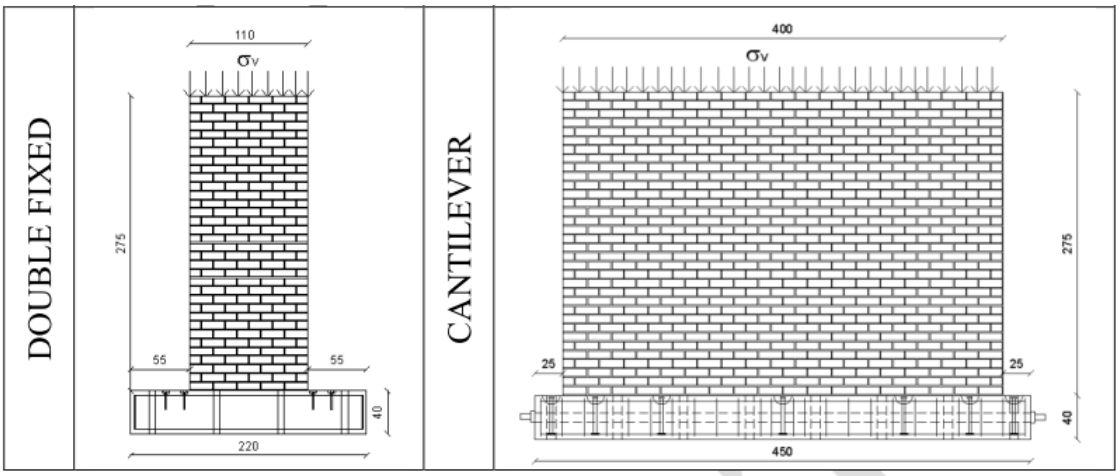

Figure 5: Experimental configurations considered, Slender Wall (left) and Squat Wall (right) (Pavese et al, 2015 [4]).

The test results presented herein are in terms of Horizontal Force – Drift/Horizontal Displacement (Figure 6 and Figure 7). More detailed results can be found in the aforementioned report (Pavese et al., 2015, [4]). As it can be inferred from their pseudo-dynamic characteristics derived from the cyclic tests, their strength should be considered adequate to withstand the frequent but mostly weak seismic events that occur in the Groningen region. As a matter of fact, this led to the necessity to further investigate the response of the tested specimens not in the range of their ultimate strength but in numerous cycles of low range of loading which may finally play an important role in the overall response during a relatively stronger event. Specifically, a thorough investigation of the tests results pointed out that nonlinear phenomena take place for very limited value of top displacements. In the Figure 6 and Figure 7, the first cycles of the conducted tests are presented for the squat wall – the results for the slender wall are equivalent and thus are not cited in this paper. It can be noticed that the unloading branches do not follow the loading one, leading thus to a small amount of residual displacements even for quite low loading. This type of response leads to an assumption that the frequent quakes that strike the structures may produce a noticeable accumulation of displacements that has the potential to be more destructive when the relatively strong ground motion occurs. This assumption will be further investigated below.

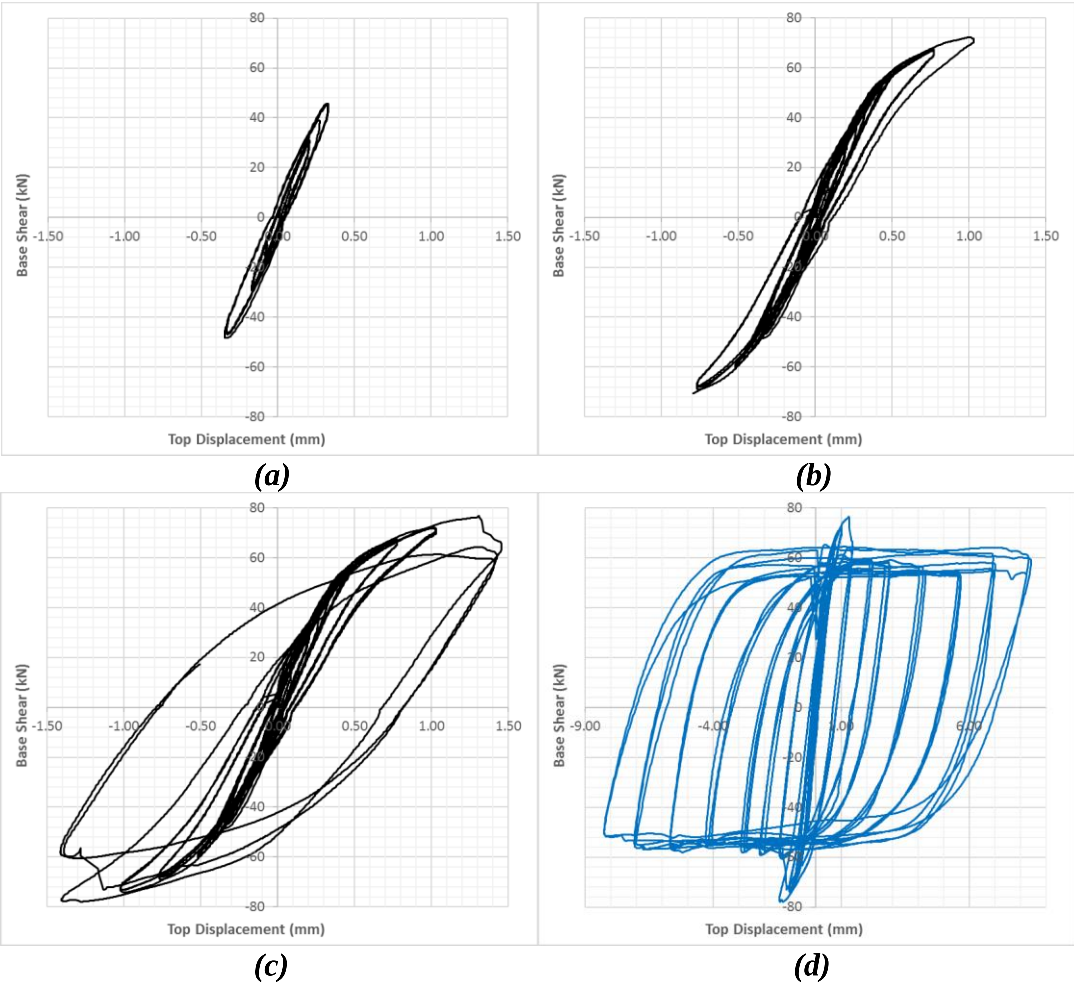

Figure 6: Experimental load deflection curve of the same EUCENTRE specimen (the squat wall specimen) focusing on different displacement ranges: (a) The first 3x3 cycles, up to 0.4mm top displacement, (b) The first 3x6 cycles up to 1mm top displacement, (c) The first 7x3 cycles up to 1.5mm top displacement, and (d) the full experimental hysteresis curve (modified from Pavese et al., 2015 report, and please note that the displacement scale of the first three plots is the same)

In order to better understand the response of the Groningen-type URM to cyclic loads, focus on the load-deflection curves are presented here in Figure 6. In evaluating the load-deflection curves in earthquake engineering practice, it is more common to concentrate on the post-yield phase of the response. In the case presented here, however, the response in the very small cycles becomes important. It can be seen in Figure 6a that the very first cycles of the squat wall (see Figure 6 for the squat wall specimen), there is a considerable amount of hysteretic energy consumed, as well as residual displacements remained on the system. In this case, the top displacement is extremely small, in the range of 0.4mm, translating into 0.01% top drift. The response becomes slightly different in Figure 6b, where the top drift ratio goes up to 0.015%, and a pinching type response is observed. The reason for this response may be either rocking of the specimen as it is, or failure of bed joints and partial rocking of the wall on one or multiple bed joints. In Figure 6c, on the other hand, ductility starts to build up leading to fatter hysteresis loops and obvious damage. When focused out to the overall response, as shown in Figure 6d, the response in the very first cycles gets invisible.

Zoom into the very first 3x3 cycles, as shown in Figure 7 (left), provides insights regarding the extremely low amplitude response of the URM walls in question. The hysteresis loops of the first cycles is quite fat, leading to residual displacement and energy consumption, so damage, in the very beginning of their response. After analyzing several cycles in the experiments, the initial backbone curve suggested for the very low amplitudes can be seen in Figure 7b. It should be noted that the main issue in this behavior, at the very beginning of the response, is the force drop when the cycles reverse. As opposed to bi-linear response, for instance, the constant is the displacement but not the load. This created practical problems in modeling these URM walls since none of the available and suitable models can consider a strength drop under constant displacement, since the hysteresis loops are mostly set for large deformations and the case is the increasing displacement under constant or slightly increasing/decreasing loads. More insights are provided on this issue in the rest of the paper.

In Figure 7 (right), in line with the experimental results, there are two characteristic behaviors that need to be addressed in a suitable hysteresis loop, which are i) at the beginning of every unloading, there is a force drop of ΔFi, and ii) the unloading stiffness is always smaller than the initial loading stiffness, thus the initial stiffness Ki is multiplied with a coefficient α, that is smaller than or equal to 1.0.

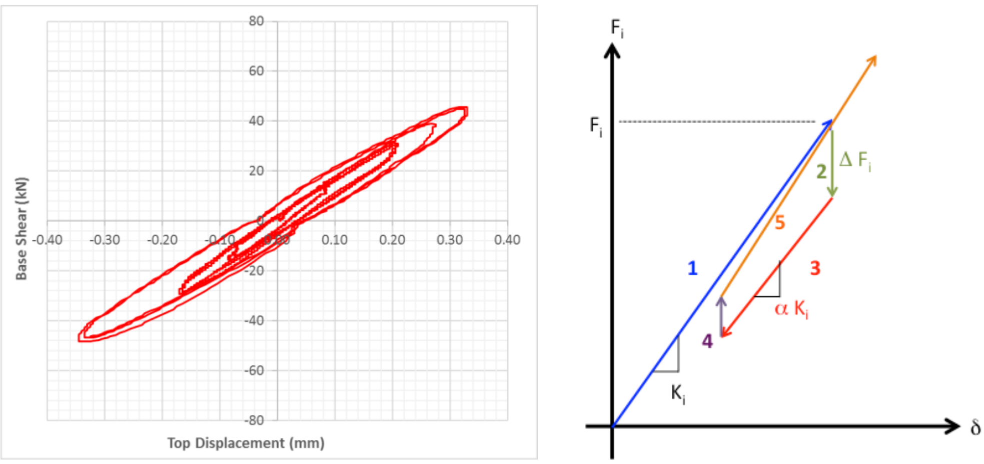

Figure 7: Focus on the experimental load deflection curve for the first 3x3 cycles (left) and an idealized hysteresis backbone (right)

4 EXERCISE WITH EXISTING HYSTERESIS LOOPS

At this point, a simple numerical model was created in the SeismoStruct software to simulate the response of the tested specimens for the very first cycles of the conducted experiments which seem to be of major importance. The Ramberg–Osgood [5, 6] constitutive model was applied on a link element, taking into consideration also the physical characteristics of the tested specimens, such as the mass, stiffness, and strength. The response of the utilized numerical model is presented in the Figure 8, comparing with the response of the corresponding specimen. Their comparison yields to a reasonable match in terms of horizontal force – top displacement response.

The calibrated model was imposed in a series of time histories. Four different scenarios were chosen:

1) The Huizinge record of 2012 (PGA=0.08g)

2) One year of all records that were recorded at the Middelstum region for in 2014 event (PGA=0.07g) followed by the Huizinge record of 2012
3) Five times the one-year of bunch that were recorded at the Middelstum region for in 2014 followed by the Huizinge record of 2012
4) Ten times the one-year of bunch that were recorded at the Middelstum region for in 2014 followed by the Huizinge record of 2012

The aforementioned scenarios were chosen this way in order to investigate the impact of the frequent but of low intensity quakes that strike the Groningen region in an annual basis to the stability of the structures when the strong event will follow.

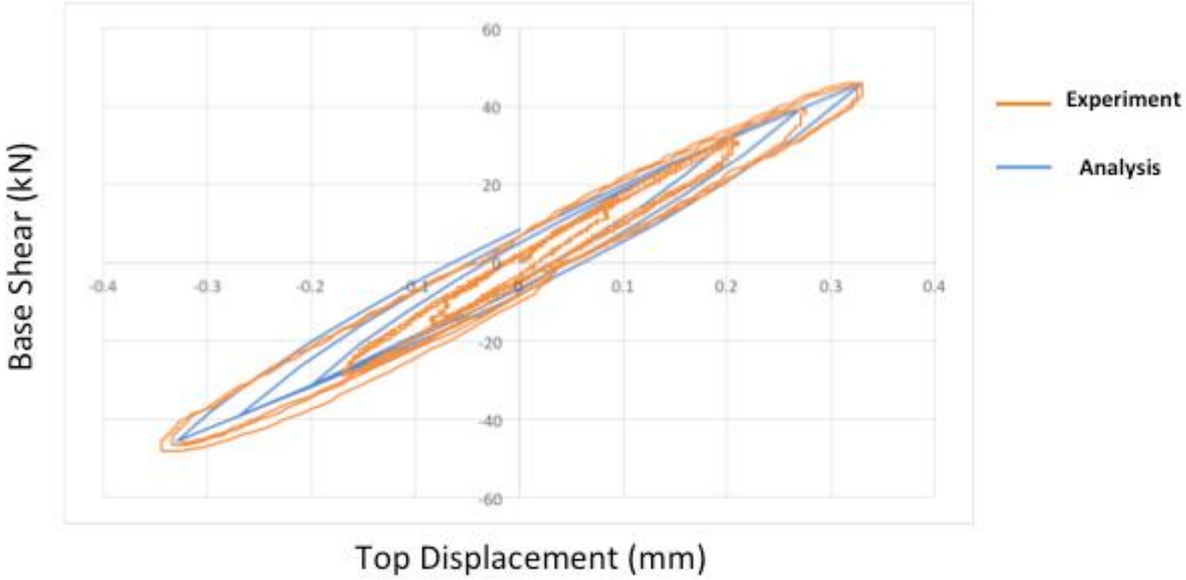

Figure 8: Calibration of the numerical model with the response of the tested specimen in terms of base shear versus top displacement for the first 3x3 cycles of the conducted experiment.

In order to explain the findings, only the results of the scenario #2 is presented here (see Figure 9 and Figure 10).

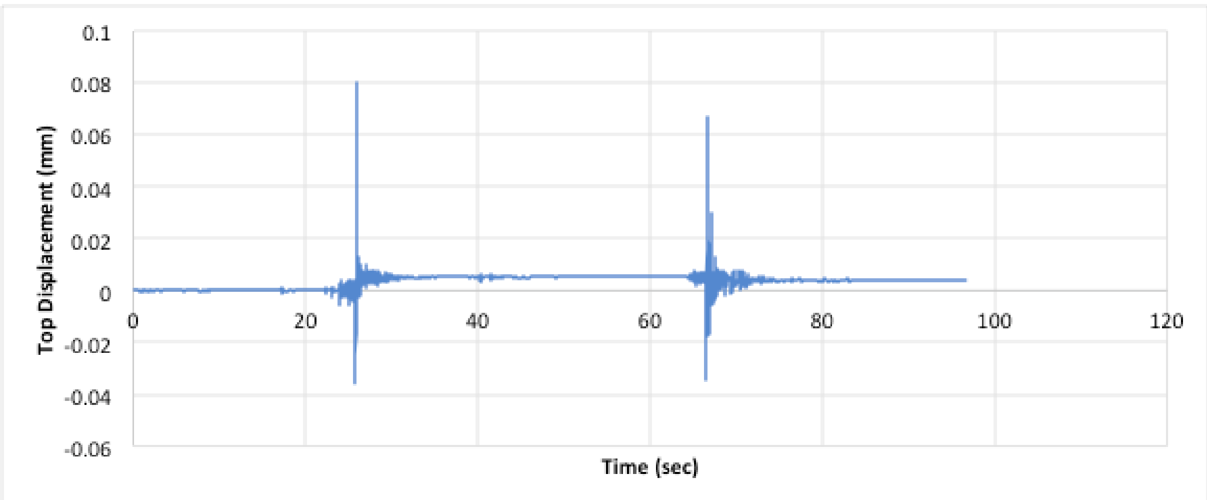

Figure 9: Top displacement time history of the squat specimen for scenario #2

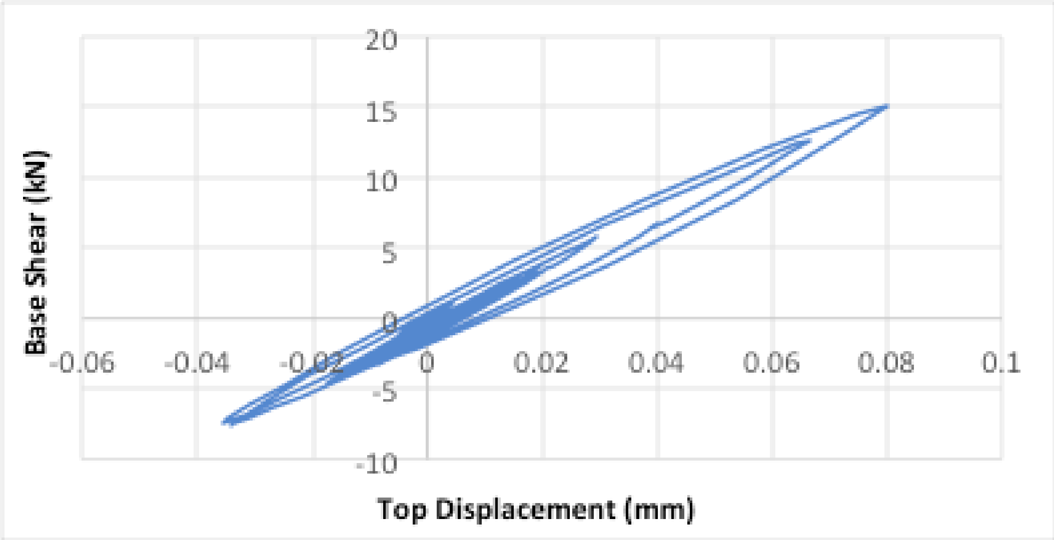

Figure 10: Top displacement versus base shear for the time history of the squat specimen for scenario #2

By using the calibrated Ramberg-Osgood model, and by applying several recursive seismic actions, it was found that the residual top displacement is approximately 0.05mm after 2014 event, and it goes down to approximately 0.025mm after the 2012 Huizinge event. Repetition of the 2014 event for 5 or 10 times does not alter this response.

This finding is not in line with the low-cycle fatigue tests with normal stresses, as reported in the literature. Additionally, after trying several hysteresis loops, the Ramberg-Osgood loop was found to be the most suitable for the very first cycles, however this model does not contain any cumulative damage parameter, leading thus to a non-realistic response where the system has tendency to re-center without accumulating damage. This is against the nature of URM material. It also should be mentioned that, even with the Ramber-Osgood parameters that fit the very first cycles, the post-yield response of the specimen was not modeled accurately.

5 CONCLUSIONS

- Experimental evidence show that the response of the Groningen-type URM walls is quite different in the very first cycles then in the post-yield phase,
- The available hysteresis loops are designed to capture more accurately the post-yield phase, and thus are not suitable for the small amplitude cycles,
- The most well calibrated model was not able to present any cumulative damage, and even has tendency to re-center, contradicting the expectations and previous experimental findings under normal stress cases,
- There is a characteristic force drop in the small amplitude cycles in case of unloading, which cannot be modeled by using the widely available common hysteresis loops,
- A special hysteresis rule that represents not only the large displacement and the post-yield phase but also the very small amplitudes need to be developed.

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REFERENCES

[1] Maqsud E Nazar, S.N. Sinha, Behaviour of interlocking grouted brick masonry under low cycle fatigue loading, *14th International Brick and Block Masonry Conference (IB2MAC 2008)*, Sydney, Australia, 17-20 February 2008.

[2] P. Ronca, A. Franchi & P. Crespi, Structural failure of historic buildings: masonry fatigue tests for an interpretation model, Structural Analysis of Historical Constructions – Modena, Lourenço & Roca (eds), 2005.

[3] Julian J Bommer, Bernard Dost, Benjamin Edwards, Pauline P Kruiver, Piet Meijers, Michail Ntinalexis, Barbara Polidoro, Adrian Rodriguez-Marek & Peter J Stafford, Technical Report (2015): Development of Version 2 GMPEs for Response Spectral Accelerations and Significant Durations from Induced Earthquakes in the Groningen Field.

[4] Experimental characterisation of calcium-silicate brick masonry for seismic assessment: Proceedings of the 16th International Brick and Block Masonry Conference, Padova, Italy, 26-30 June 2016

[5] Ramberg W., Osgood W.R. [1943] Description of Stress-Strain Curves by Three Parameters, National Advisory Committee on Aeronautics, Technical Note 902.

[6] SeismoStruct v7.0 - User Manual.